Stochastic Simulation of Sea-state Propagating in the Ocean Based on Hindcast Data

Munehiko Minoura and Shigeru Naito
Department of Naval Architecture and Ocean Engineering, Osaka University
Osaka, Japan

ABSTRACT

Sea-states are assumed to be separated into independent components. A stochastic model based on the Markov process that includes a seasonal model is applied to these independent components. The propagation of a sea-state in the ocean is represented by the cross-correlation between present and past sea-states. The correlation is provided by sea-states with a given time step. A comparison of the occurrence probability and cross-correlation of the sea-states between simulations using our proposed stochastic model and the hindcast data shows that our proposed stochastic model and simulation scheme are valid. We observe a high sea area propagating from the west to the east in our simulations, as observed in actual seas.

KEY WORDS: sea-state, wave statistics, Markov process, stochastic differential equation, probability density function, independent component, eigenvalue decomposition

INTRODUCTION

Sea-states used in the design and operation of ships and marine systems are provided in the form of statistical information from ocean waves and winds. A sea-state is represented by several parameters. For example, significant wave height or mean wave period is a sea-state parameter. The long-term occurrence probabilities and cross-correlations of sea-state parameters are commonly provided as wave tables, such as the Global Wave Statistics and the Waves and Winds in the North Pacific Ocean, which are constructed from a number of accumulated observation data and from hindcast data. These wave tables are useful for evaluating the lifetime of ships (Fukuda, 1969, Nordenström, 1973, Naito et al., 1998, 2006).

Oceangoing cargo ships are becoming more sophisticated and larger. This is a result of the optimization of sea transportation. A more accurate evaluation of the structural strength, hydrodynamic performance, and operating cost is naturally desired, because these ships have a large influence on several aspects of safety and economy. For example, it is desirable to compare fuel consumption and arrival time, depending on the route, season, operating criteria. In general, wave tables that cover wide sea areas are not suitable for this purpose, and historical sea-state data on the sea routes where these ships sail is required.

An oceangoing simulation in a time domain is a powerful tool for this purpose (Dallinga et al., 2004). Sea-state data used in our simulations are the common historical hindcast data covering a period of several years. Hindcast data have been assimilated with observational data at specific sea locations. This hindcast data forms a single datum because the observational data is classed as a single sample. Assuming that the variation of a sea-state over time is a stochastic process, then more samples are required. However, most oceangoing simulations have been performed using a single sample composed of the historical hindcast data.

Minoura and Naito (2004, 2006) proposed a stochastic process model (i.e., a mathematical model) of sea-states to simulate historical sea-states. The proposed model was based on the Markov process. The model parameters were identified from hindcast sea-state data having a duration of several years. The parameters were obtained from either historical data or statistical data, because the stochastic model was expressed as either a stochastic differential equation or as a probability density function. This model enabled the simulation of many sea-states that had the same stochastic properties as the hindcast data.

However, this model is not adequate for oceangoing simulations because it only provides sea-states at a single sea location and winds generate and propagate waves at sea. In the North Pacific Ocean, wave groups tend to propagate from the west to the east, caused by the westerlies, and as a consequence the sea-states seem to propagate. An oceangoing simulation needs to incorporate this sea-state propagation. This requires a sea-state at a particular sea location to vary with the cross-correlations with other sea-states at another location. Therefore, in practice, the cross-correlation of sea-states in space and time must be constructed into any stochastic models.

In this work, the sea-states are assumed to be able to be separated into independent components. A stochastic model based on the Markov process that includes a seasonal model is applied to these independent components. The propagation of the sea-